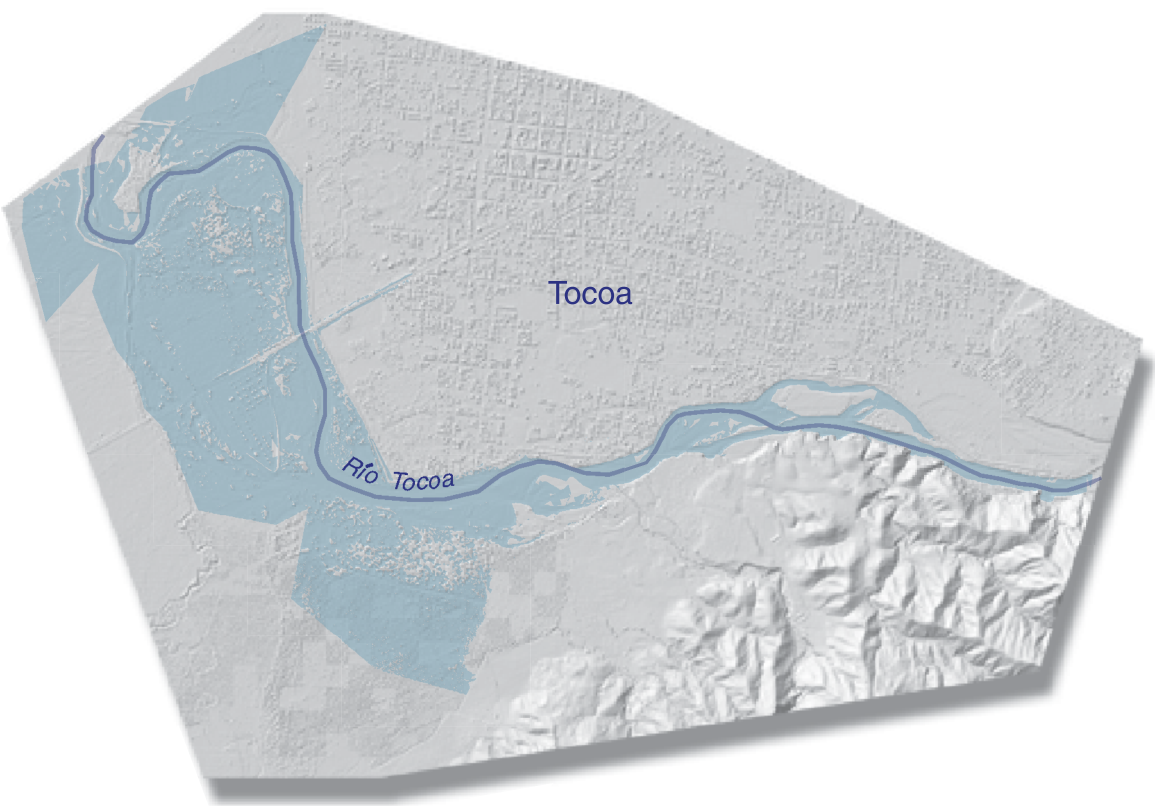
Prepared in cooperation with the U.S Agency for International Development

Fifty-Year Flood-Inundation Maps for Tocoa, Honduras

U.S. Geological Survey Open-File Report 02-262



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U.S. Department of the Interior
U.S. Geological Survey

Fifty-Year Flood-Inundation Maps for Tocoa, Honduras

By David L. Kresch, Mark C. Mastin, and Theresa D. Olsen

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 02-262

Prepared in cooperation with the
U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT

Tacoma, Washington
2002

U.S. DEPARTMENT OF THE INTERIOR
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CONVERSION FACTORS AND VERTICAL DATUM

CONVERSION FACTORS

Multiply	By	To obtain
cubic meter per second (m^3/s)	35.31	cubic foot per second
kilometer (km)	0.6214	mile
meter (m)	3.281	foot
millimeter (mm)	0.03937	inch
square kilometer (km^2)	0.3861	square mile

VERTICAL DATUM

Elevation: In this report "elevation" refers to the height, in meters, above the ellipsoid defined by the World Geodetic System of 1984 (WGS 84).

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ABSTRACT

After the devastating floods caused by Hurricane Mitch in 1998, maps of the areas and depths of the 50-year-flood inundation at 15 municipalities in Honduras were prepared as a tool for agencies involved in reconstruction and planning. This report, which is one in a series of 15, presents maps of areas in the municipality of Tocoa that would be inundated by a 50-year flood of Río Tocoa. Geographic Information System (GIS) coverages of the flood inundation are available on a computer in the municipality of Tocoa as part of the Municipal GIS project and on the Internet at the Flood Hazard Mapping Web page (http://mitchnts1.cr.usgs.gov/projects/floodhazard.html). These coverages allow users to view the flood inundation in much more detail than is possible using the maps in this report.

Water-surface elevations for an estimated 50-year-flood on Río Tocoa at Tocoa were estimated using HEC-RAS, a one-dimensional, steady-flow, step-backwater computer program. The channel and floodplain cross sections used in HEC-RAS were developed from an airborne light-detection-and-ranging (LIDAR) topographic survey of the area and a ground survey at one bridge. There are no nearby long-term streamgaging stations on Río Tocoa; therefore, the 50-year-flood discharge for Río Tocoa, 552 cubic meters per second, was estimated using a regression equation that relates the 50-year-flood discharge to drainage area and mean annual precipitation. The drainage area and mean annual precipitation estimated for Río Tocoa at Tocoa are 204 square kilometers and 1,987 millimeters, respectively. It was assumed that a portion of the 50-year flood, 200 cubic meters per second, would escape the main channel and flow down a side channel before re-entering the main channel again near the lower end of the study area.

INTRODUCTION

In late October 1998 Hurricane Mitch struck the mainland of Honduras, triggering destructive landslides, flooding, and other associated disasters that overwhelmed the country’s resources and ability to quickly rebuild itself. The hurricane produced more than 450 millimeters (mm) of rain in 24 hours in parts of Honduras and caused significant flooding along most rivers in the country. A hurricane of this intensity is a rare event, and Hurricane Mitch is listed as the most deadly hurricane in the Western Hemisphere since the “Great Hurricane” of 1780. However, other destructive hurricanes have hit Honduras in recent history. For example, Hurricane Fifi hit Honduras in September 1974, causing 8,000 deaths (Rappaport and Fernandez-Partagas, 1997).

As part of a relief effort in Central America, the U.S. Agency for International Development (USAID), with help from the U.S. Geological Survey (USGS), developed a program to aid Central America in rebuilding itself. A top priority identified by USAID was the need for reliable flood-hazard maps in Honduras to help plan the rebuilding of housing and infrastructure. The Water Resources Division of the USGS in Washington State, in coordination with the International Water Resources Branch of the USGS, was given the task to develop flood-hazard maps for 15 municipalities in Honduras: Catacamas, Choloma, Choluteca, Comayagua, El Progreso, Juticalpa, La Ceiba, La Lima, Nacaome, Olanchito, Santa Rosa de Aguán, Siguatepeque, Sonaguera, Tegucigalpa, and Tocoa. This report presents and describes the determination of the area and depth of inundation in the municipality of Tocoa that would be caused by a 50-year flood of Río Tocoa.

The 50-year flood was used as the target flood in this study because discussions with the USAID and the Honduran Public Works and Transportation Ministry indicated that it was the most common design flood used by planners and engineers working in Honduras. The 50-year flood is one that has a 2-percent chance of being equaled or exceeded in any one year and on average would be equalled or exceeded once every 50 years.

Purpose, Scope, and Methods

This report provides (1) results and summary of the hydrologic analysis to estimate the 50-year-flood discharge used as input to the hydraulic model, (2) results of the hydraulic analysis to estimate the water-surface elevations of the 50-year-flood discharge at cross sections along the stream profile, and (3) 50-year-flood inundation maps for Río Tocoa at Tocoa showing area and depth of inundation.

The analytical methods used to estimate the 50-year-flood discharge, to calculate the water-surface elevations, and to create the flood-inundation maps are described in a companion report by Mastin (2002). Water-surface elevations along Río Tocoa were calculated using a one-dimensional, steady-flow, step-backwater computer model; and maps of the area and depths of inundation were generated from the water-surface elevations and topographic information.

The channel and floodplain cross sections used in the model were developed from an airborne light-detection-and-ranging (LIDAR) topographic survey of Tocoa and ground surveys at the bridge. Because of the high cost of the LIDAR elevation data, the extent of mapping was limited to areas of high population where flooding is expected to cause the worst damage. The findings in this report are based on the condition of the river channel and floodplains on March 12, 2000, when the LIDAR data were collected and on January 16, 2001, when the bridge was surveyed.

Acknowledgments

We acknowledge USAID for funding this project; Jeff Phillips of the USGS for providing data and field support while we were in-country; Roger Bendeck, a Honduran interpreter, for being an indispensable guide, translator, and instrument man during our field trips; and the people of Tocoa, including the mayor, Carlos Hernan Banegas, who gave us important local insights to the river hydrology.

DESCRIPTION OF STUDY AREA

Río Tocoa flows along the southern and western boundary of the city of Tocoa. The study area includes the floodplain of Río Tocoa from approximately 2 kilometers (km) upstream from its mouth, where it flows into Río Aguán, to approximately 6.0 km further upstream at the southeastern part of the city at the foothills of Montaña de Garcia (figure 1), and includes the lower portion of a stream, Quebrada de Ceibita.

The streambed material ranges from gravel to cobbles in the upper end of the study reach to mostly sand at the lower end. The main-channel banks and floodplains are either grassy fields, orchards, or dense natural forest. A highway crosses the river at the southwest corner of the urbanized area. On the right bank (looking downstream), constructed levees extend about 1.5 km upstream and downstream of the bridge crossing; another levee extends about 0.5 km upstream of the bridge on the left bank, and a levee extends about 1 km upstream from the lower end of the study area along the left bank of Río Tocoa and Quebrada de Ceibita.

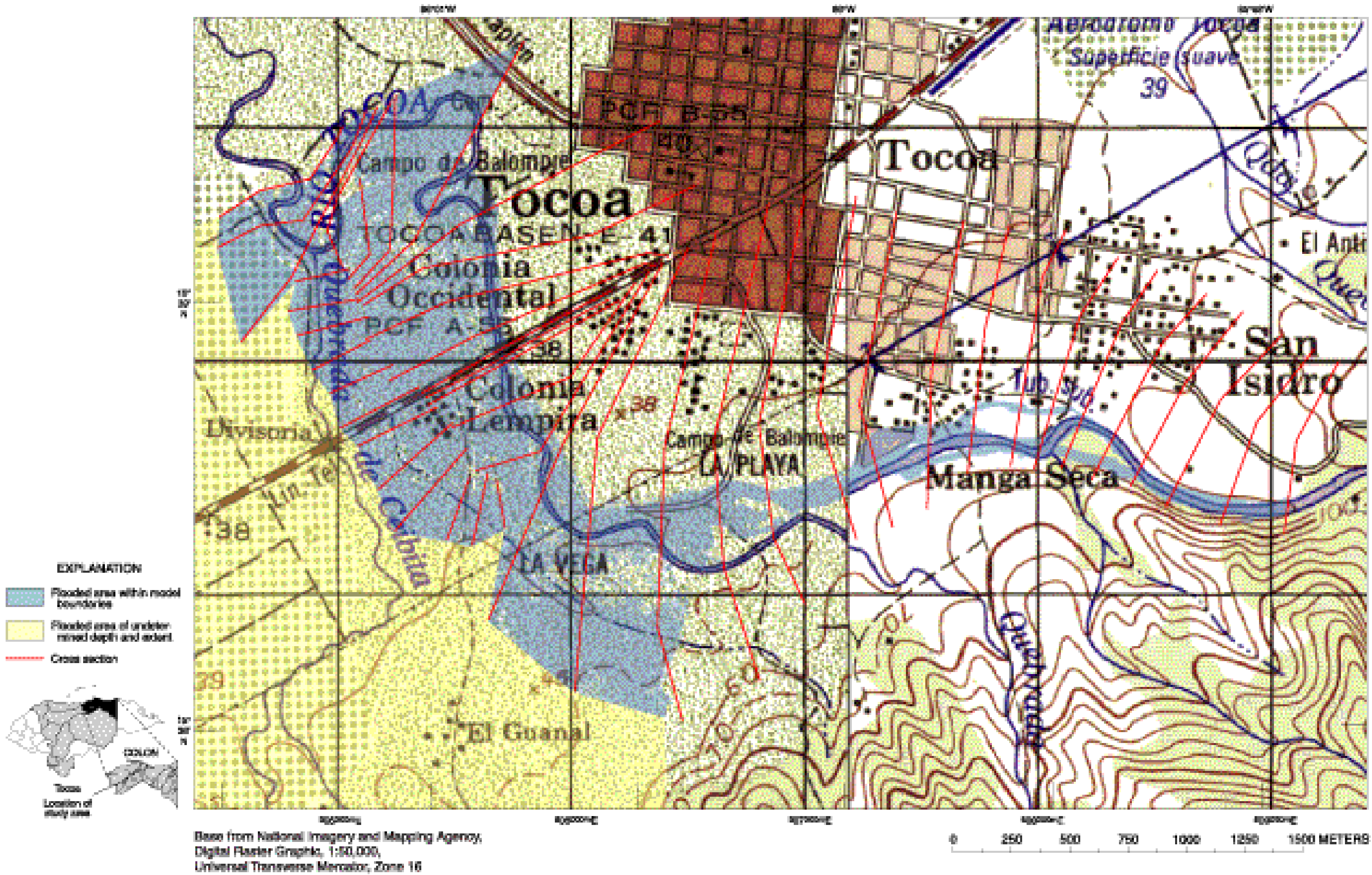

Figure 1. Location of study area and cross sections, and the area of inundation for the 50-year flood on Río Tocoa at Tocoa, Honduras.

FIFTY-YEAR FLOOD DISCHARGE

There are no long-term streamflow records for Río Tocoa. Therefore, the 50-year-flood discharge was estimated using the following regression equation, which was developed using data from 34 streamflow stations throughout Honduras with more than 10 years of annual peak flow record, that relates the 50-year peak flow with drainage basin area and mean annual precipitation (Mastin, 2002).

$$Q_{50} = 0.0788(DA)^{0.5664}(P)^{0.7693}\,, \qquad (1)$$

where

Q_{50} is the 50-year-flood discharge, in cubic meters per second (m^3/s),

DA is drainage area, in square kilometers (km^2), and

P is mean annual precipitation over the basin, in mm.

The standard error of estimate of equation 1, which is a measure of the scatter of data about the regression equation, is 0.260 log unit, or 65.6 percent. The standard error of prediction, which is a measure of how well the regression equation predicts the 50-year-flood discharge and includes the scatter of the data about the equation plus the error in the regression equation, equals 0.278 log unit, or 71.3 percent.

The drainage area of Río Tocoa at Tocoa was determined to be 204 km^2 using a geographic information system (GIS) program to analyze a digital elevation model (DEM) with a 93-meter cell resolution from the U.S. National Imagery and Mapping Agency (David Stewart, USGS, written commun., 1999). The mean annual precipitation over the Río Tocoa drainage basin was determined to be 1,987 mm using a GIS program to analyze a digitized map of mean annual precipitation at a scale of 1:2,500,000 (Morales-Canales, 1997–1998, p. 15).

The 50-year-flood discharge estimated from equation 1 for Río Tocoa at Tocoa is 552 m^3/s.

WATER-SURFACE PROFILES OF THE 50-YEAR FLOOD

Once a 50-year flood discharge has been estimated, a profile of water-surface elevations along the course of the river can be estimated for the 50-year flood with a step-backwater model, and later used to generate the flood-inundation maps. The U.S. Army Corps of Engineer's HEC-RAS modeling system was used for step-backwater modeling. HEC-RAS is a one-dimensional, steady-flow model for computing water-surface profiles for open channels, through bridge openings, and over roads. The basic required inputs to the model are stream discharge, cross sections (geometry) of the river channels and floodplains perpendicular to the direction of flow, bridge geometry, Manning's roughness coefficients (*n* values) for each cross section, and boundary conditions (U.S. Army Corps of Engineers, 1998). There is only one bridge in the study reach, and it is located at the main highway crossing (cross section 2.210).

Cross-section geometry was obtained from a high-resolution DEM created from LIDAR and a ground survey at the bridge. The LIDAR survey was conducted by personnel from the University of Texas. A fixed-wing aircraft with the LIDAR instrumentation and a precise global positioning system (GPS) flew over the study area on March 12, 2000. The relative accuracy of the LIDAR data was determined by comparing LIDAR elevations with GPS ground-surveyed elevations at 341 points in the Tocoa study area. The mean difference between the two sets of elevations is 0.182 meter, and the standard deviation of the differences is 0.093 meter. The LIDAR data were filtered to remove vegetation while retaining the buildings to create a "bare earth" elevation representation of the floodplain. The LIDAR data were processed into a GIS (Arc/Info™) GRID raster coverage of elevations at a 1.5-meter cell resolution. The coverage was then processed into a triangular irregular network (TIN) GIS coverage. Cross sections of elevation data oriented across the floodplain perpendicular to the expected flow direction of the 50-year-flood discharge (figure 1) were obtained from the TIN using HEC-GeoRAS, a pre- and post-processing GIS program. The left overbank of Río Tocoa just downstream of the highway bridge and another left overbank region in the center of the study area contain orange groves that were not entirely removed when the vegetation filter was applied to the LIDAR data. Manual editing of the cross-section data in these areas lowered the peaks in the cross section created from tree-top elevations to surrounding ground elevations. An example of an edited cross section is shown on figure 2.

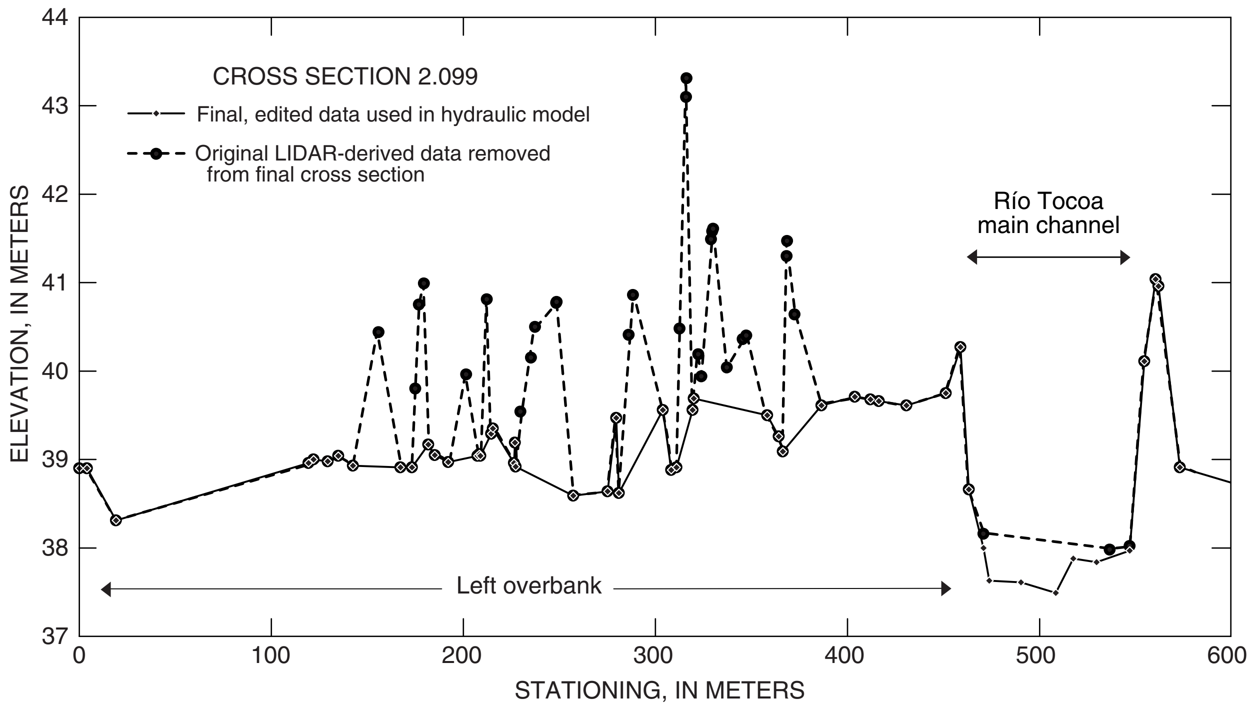

Figure 2. Example of a LIDAR-derived cross section of Río Tocoa, Honduras, that was edited to remove elevation peaks assumed to represent the tops of orange trees and to add the underwater portion not detected by LIDAR.

The underwater portions of the cross sections, which cannot be seen by the LIDAR system, were estimated using data from a ground survey, conducted January 16, 2001, of a river cross section approximately 36 meters downstream from the highway bridge. The surveyed underwater portion was 44.8 meters wide with a maximum depth of 0.83 meter, and had an area of 19.7 m^2. These estimated underwater data were added to each of the LIDAR-derived cross sections on Río Tocoa at the end points of the flat channel bottom perceived to be the water surface (figure 2). The area and general shape of the field-surveyed underwater part of the cross section was maintained at each of the cross sections. A ground survey also was made of a cross section at the highway bridge to define the size of the bridge openings. The cross section obtained using the data from this survey replaced the LIDAR-derived cross section at this location.

Tocoa was the only study area of the 15 municipalities for which the underwater portion of the cross section was estimated and then added to the hydraulic model, because of the limited flow capacity of the highway bridge opening that was filled with sediment during the Hurricane Mitch flood. When the model was first constructed, using the ground-surveyed cross sections with the underwater portions at the bridge's upstream and downstream openings and the unmodified, LIDAR-derived cross sections elsewhere, the profile of the channel thalweg (deepest point in channel cross section) for the entire reach showed a prominent downward dip at the bridge. Using the underwater portion throughout the Tocoa reach instead produced a more realistic profile of the channel thalweg, especially in the vicinity of the bridge.

Most hydraulic calculations of flow in channels and overbank areas require an estimate of flow resistance, which is generally expressed as Manning's roughness coefficient, *n*. The effect that roughness coefficients have on water-surface profiles is that as the *n* value is increased, the resistance to flow increases, which results in higher water-surface elevations. Roughness coefficients for Río Tocoa were estimated from field observations and digital photographs taken during the field visit on January 16, 2001, and from computer displays of shaded-relief images of the LIDAR-derived DEM before a vegetation removal filter was applied. The *n* values estimated for the main channel of Río Tocoa ranged from 0.030 to 0.037, and the *n* values estimated for the floodplain areas ranged from 0.045 to 0.080. Low-grass areas on the overbanks were given the lowest *n* values, areas with orchards were given values in the middle of the range, and areas with dense natural forest were given the highest values.

Step-backwater computations require a water-surface elevation at either the downstream end of the stream reach for flows in the subcritical flow regime or at the upstream end of the reach for flows in the supercritical flow regime as a boundary condition. Initial HEC-RAS simulations indicated that the flow in Río Tocoa would be in the subcritical flow regime. A water-surface elevation of 37.39 meters at cross section 0.096, the farthest downstream cross section in the Río Tocoa step-backwater model, was estimated by a slope-conveyance computation assuming an energy gradient of 0.002. The energy gradient was estimated to be equal to the slope of the main channel bed. The computed water-surface elevations at the first few cross sections upstream may differ from the true elevations if the estimated boundary condition elevation is incorrect. However, if the error in the estimated boundary condition is not large, the computed profile asymptotically approaches the true profile within a few cross sections.

If Río Aguán is flooding at the same time as Río Tocoa, the flooding on Río Aguán might cause backwater at cross section 0.085, resulting in a higher surface profile than the model estimates, which would result in a larger area of inundation than indicated in figure 1. It was reported (Carlos Hernan Banegas, mayor of Tocoa, oral commun., 1999) that Río Aguán flooded areas in Tocoa on the north side of the city during Mitch Hurricane. The elevation of this area is approximately 38 meters or lower, or about 0.6 meter higher than the boundary condition used for the Río Tocoa model. However, floods on Río Aguán that would cause backwater effects on the surface-water profile presented in this report are probably less likely to occur than the 50-year peak flow, based on the following observations.

A few observations are available to provide an insight to the magnitude of the Hurricane Mitch flood on Río Aguán. The flood on Río Aguán caused by Hurricane Mitch had an estimated discharge of 19,700 m^3/s near Clifton, a site upstream of Tocoa with a drainage area of 7,460 km^2 (Mark Smith, U.S. Geological Survey, written commun., April 2001). For the 1974 Hurricane Fifi flood at a location on the Río Aguán system downstream of Tocoa, Sir William Halcrow and Partners (1985) estimated a combined discharge of 1,750 m^3/s in Río Aguán above Puente Durango and a distributary Río Chapagua with a combined drainage area of 9,850 km^2. They estimated that this flood approximates a 25-year flood. They also show a figure with a 50-year peak-flow estimate of 4,700 m^3/s on Río Aguán at Puente Saba, a site located about 19 km downstream of Clifton, based on a model by SOGREAH (Sir William Halcrow and Partners, 1985, p. H.194). Using the regression equation (eq. 1) developed to estimate the 50-year peak flow, the estimated 50-year peak flow for Río Aguán near Clifton is 3,270 m^3/s and at Puente Durango is 3,980 m^3/s. It appears that the Hurricane Mitch flood, which probably affected the downstream boundary conditions on the study reach for Río Tocoa, was more than five times the discharge of the estimated 50-year peak flow.

The Río Tocoa step-backwater model provides estimates of water-surface elevations at all cross sections for the 50-year-flood discharge (table 1 and figures 3 and 4). The model indicates that water flows over the southwest bank of the main channel of Río Tocoa just downstream of cross section 2.928 and down a side channel that connects with Quebrada de Ceibita. The side channel was added to the model in order to simulate flow down this channel and then back into the main channel upstream of cross section 0.442. No information about the flow structure under the highway at the side channel was available for input to the model. Several trial-and-error model runs were made with various combinations of discharge for the side channel and for the middle reach of Río Tocoa, totalling 552 m^3/s, until the water-surface elevations matched at their upstream ends. The water-surface elevation at cross section 0.442 was used as the downstream boundary condition. The final model run simulates 352 m^3/s flowing down the main channel of Río Tocoa and 200 m^3/s down the side channel.

The model output shows a major constriction of water through the highway bridge opening, causing high surface-water elevations upstream of the bridge that approach the elevation of the top of the existing levee. The surface-water elevation is slightly above the low-chord elevation of the bridge, a precariously high level where small obstructions to flow or slight increases in discharge may cause a water-level rise that could overtop the bridge or the nearby levees. Downstream of the bridge, water elevations of the estimated 50-year peak flow are slightly below the elevation of the top of the existing levee on the east side of the river, which confines flood waters that would otherwise inundate the northwest part of the city of Tocoa. This is based on the assumption that there are no breaks in the levee and that it does not fail during the flood.

Table 1. Estimated water-surface elevations for the 50-year flood for cross sections along Río Tocoa at Tocoa, Honduras

[**Cross-section stationing**: distance upstream from an artibrary point near the model boundary; **Minimum channel elevation**, **Water-surface elevation**: elevations are referenced to the World Geodetic System Datum of 1984; **Abbreviations**: km, kilometers; m, meters; m/s, meters per second; m/^{3}s, cubic meters per second]

Cross-section stationing (km)	50-year peak flow (m^3/s)	Minimum channel elevation (m)	Average velocity of flow (m/s)	Water-surface elevation (m)
Río Tocoa upstream of side-channel inflow				
6.430	552	60.06	3.69	62.27
6.158	552	57.41	4.13	59.98
5.920	552	54.97	4.30	57.74
5.744	552	52.58	3.92	56.16
5.580	552	51.75	3.60	55.39
5.434	552	49.34	4.90	53.77
5.314	552	49.20	2.26	52.70
5.197	552	49.21	4.21	51.56
5.000	552	47.09	2.42	50.16
4.810	552	45.81	3.59	48.53
4.527	552	42.47	2.68	46.90
4.291	552	41.45	3.59	45.18
3.972	552	41.34	2.97	42.85
3.747	552	39.62	1.64	42.56
3.476	552	39.28	1.43	42.31
3.167	552	39.13	2.78	41.51
2.928	552	38.74	0.96	41.40
Río Tocoa between side-channel outflow and inflow				
2.679	352	38.15	1.22	41.14
2.425	352	38.22	1.17	40.96
2.258	352	37.79	1.24	40.84
2.215	352	36.95	0.90	40.86
2.210 (bridge)				
2.197	352	36.95	2.25	40.08
2.099	352	37.49	1.37	40.02
1.932	352	36.92	0.99	39.84
1.780	352	37.09	1.07	39.62
1.589	352	36.68	0.99	39.49
1.336	352	36.31	0.88	39.34
1.034	352	35.04	1.06	39.03
0.896	352	34.98	1.32	38.87
0.594	352	34.76	1.98	38.34
Río Tocoa downstream of side-channel outflow				
0.442	552	34.42	2.45	37.89
0.265	552	34.48	1.40	37.70
0.096	552	34.29	1.63	37.39
Side channel				
1.479	200	39.60	1.02	41.15
1.397	200	39.08	0.62	41.06
1.311	200	38.41	0.71	40.98
1.182	200	38.05	1.12	40.77
1.028	200	38.38	0.71	40.68
0.821	200	37.33	0.57	40.60
0.713	200	37.37	0.65	40.56
0.567	200	36.76	0.71	40.52
0.434	200	36.69	0.55	40.51
0.302	200	36.46	1.77	40.31
0.202	200	36.26	2.34	39.76
0.071	200	35.94	2.09	38.62

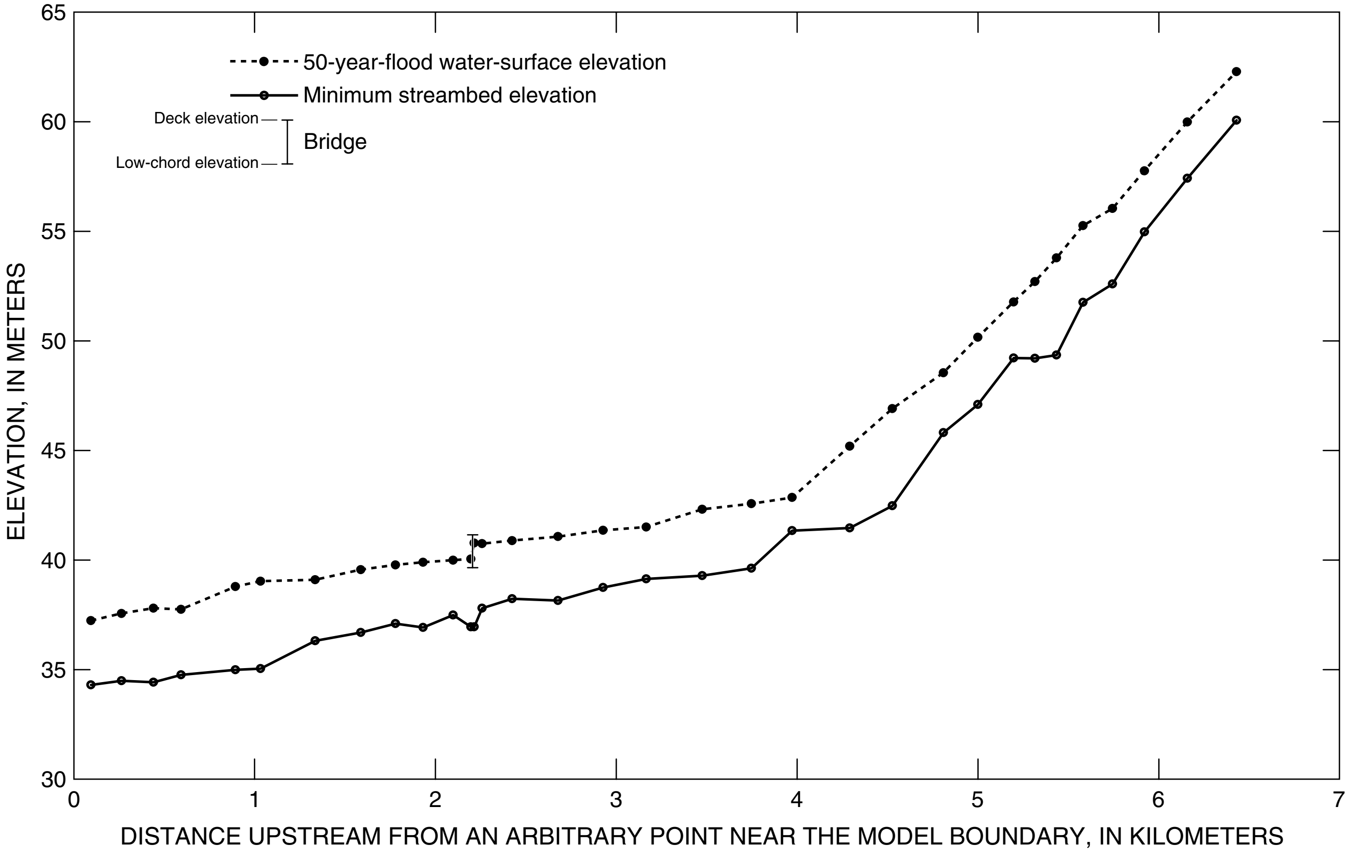

Figure 3. Water-surface profile, estimated using the step-backwater model HEC-RAS, for the 50-year flood on the main channel on Río Tocoa at Tocoa, Honduras.

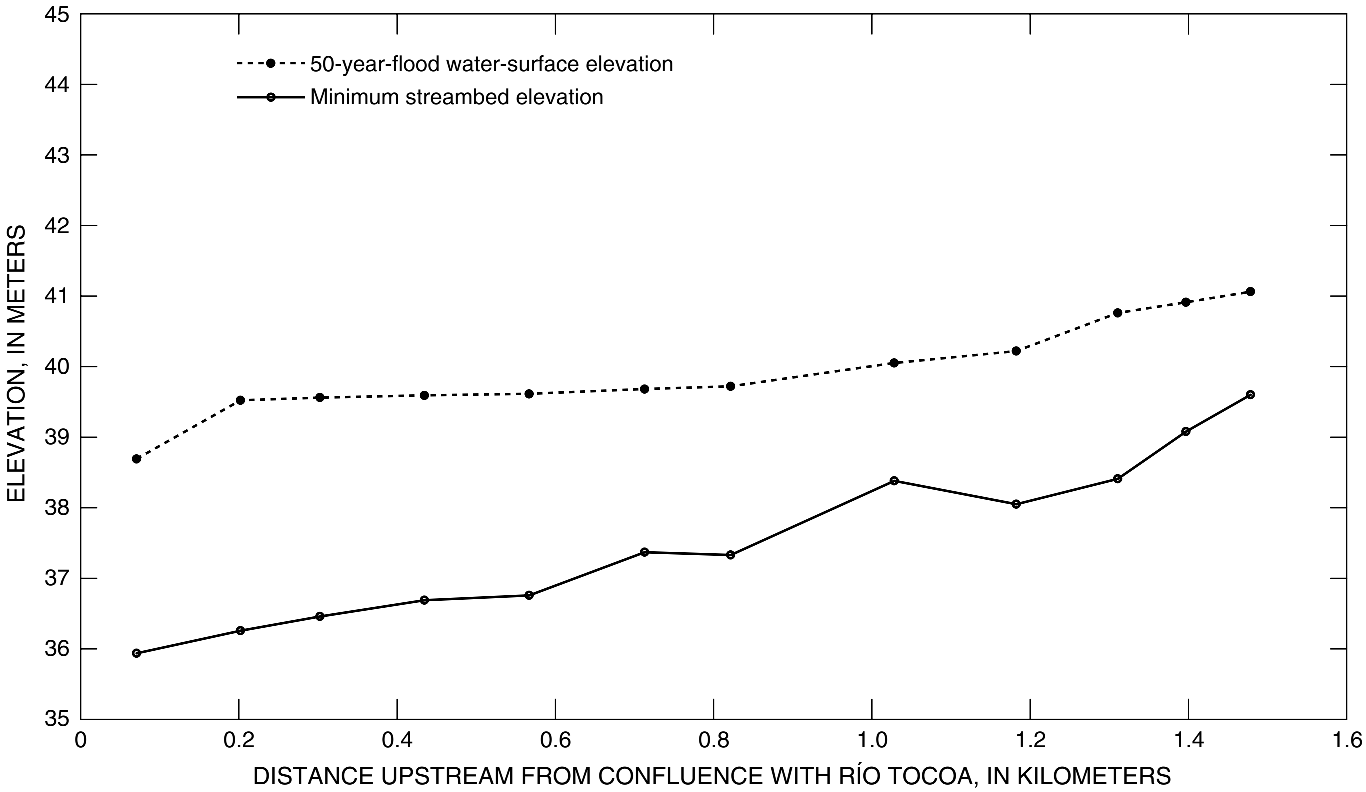

Figure 4. Water-surface profile, estimated using the step-backwater model HEC-RAS for the 50-year flood on the side channel on Río Tocoa at Tocoa, Honduras.

FIFTY-YEAR FLOOD-INUNDATION MAPS

The results from the step-backwater hydraulic model were processed by the computer program HEC-GeoRAS to create GIS coverages of the area and depth of inundation for the study area. The GIS coverage of area of inundation was created by intersecting the computed water-surface elevations with the topographic TIN that was produced from the LIDAR data. This coverage was overlain on an existing 1:50,000 topographic digital raster graphics map (figure 1) produced by the National Imagery and Mapping Agency (Gary Fairgrieve, USGS, written commun., 1999). Depth of inundation for the 50-year flood (figure 5) was computed by subtracting the topographic TIN from a computed water-surface elevation TIN to produce a grid with a cell size of 2.0 meters. Depths of inundation in the areas believed to be orange groves on the left overbank areas between cross sections 1.034 and 2.197 and between cross sections 2.928 and 3.476 may be underestimated because some of the elevation values in the topographic TIN for these areas may represent the tree tops rather than the ground surface.

The area of inundation shown in figures 1 and 5 extends only to the outer ends of the cross sections, but flooding of undetermined depth and extent will occur beyond the extent of the cross sections to the west of the study area starting from cross section 3.476 and extending downstream to Río Aguán, and north of the levee in the vicinity of the cross section 0.654 at an apparent break in the levee. It was impossible to estimate the discharge of this flooding with a reasonable accuracy, so no reduction in discharge was applied to model to account for this water loss to the main channel.

The blue lines depicting the Río Tocoa channel on the digital raster graphics map used as the base map for figure 1 lie outside the 50-year-flood boundaries at some locations. This probably results from changes in the river course as a result of flood flows that occurred after the map was created, especially those that resulted from Hurricane Mitch. Shifting of the river channel is suggested by the obvious mismatch in the location of Río Tocoa at longitude 86°N near the center of figure 1, where two base maps, made at different times, were joined.

The flood-hazard maps are intended to provide a basic tool for planning or for engineering projects in or near the Río Tocoa floodplain. This tool can reasonably separate high-hazard from low-hazard areas in the floodplain to minimize future flooding losses. However, significant introduced or natural changes in main-channel or floodplain geometry or location can affect the area and depth of inundation. Also, encroachment into the floodplain with structures or fill will reduce flood-carrying capacity and thereby increase the potential height of floodwaters, and may increase the area of inundation. In the area between the main channel and the side channel, some mixing of the two flows is probably occurring, and a two-dimensional model would be required to model water-surface elevations correctly. Where mixing is occurring, the one-dimensional model used in this analysis may be incorrectly simulating water-surface elevations.

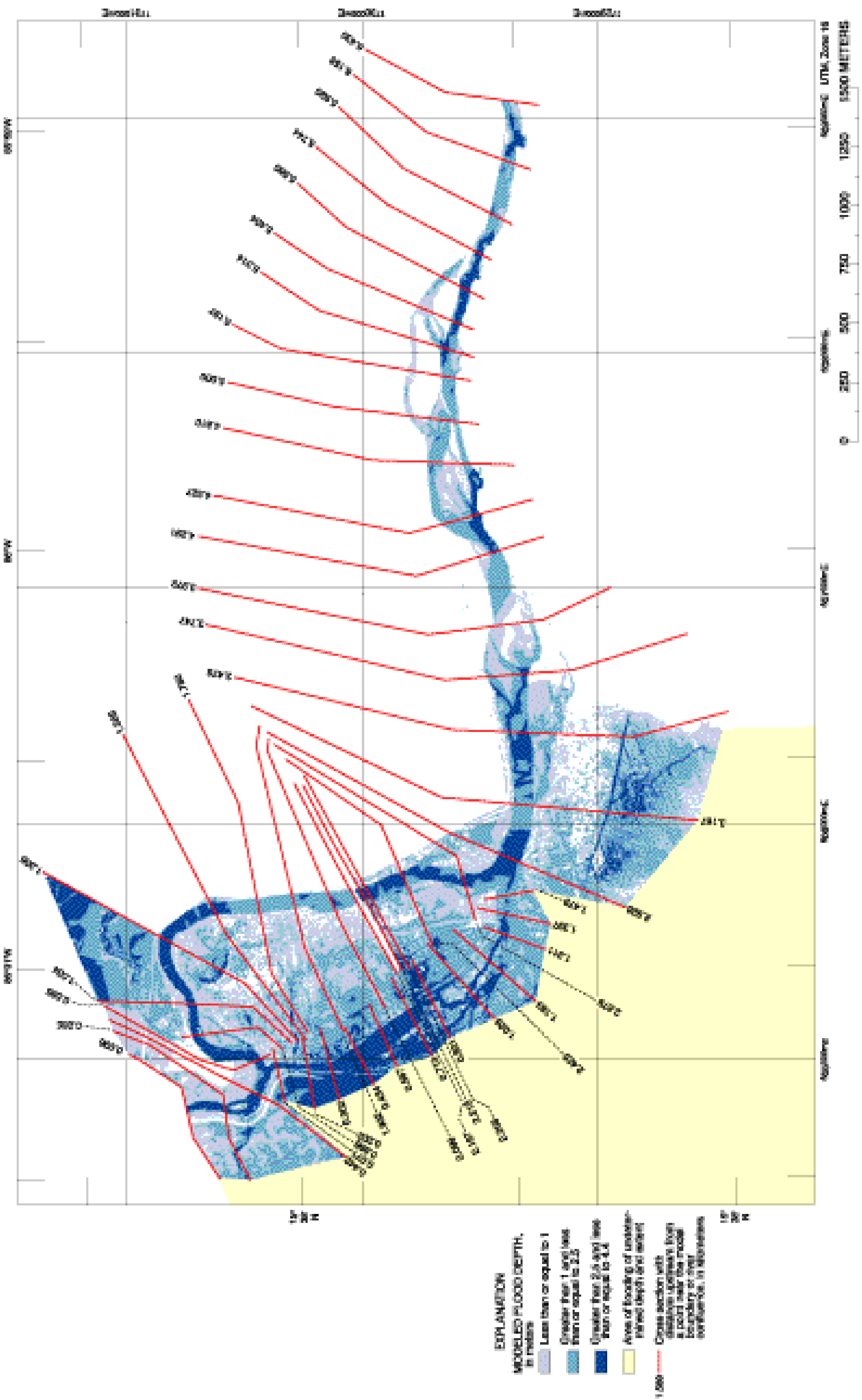

Figure 5. Depth of inundation for the 50-year flood and location of cross sections on Río Tocoa at Tocoa, Honduras.

DATA AVAILABILITY

GIS coverages of flood inundation and flood depths shown on the maps in figures 1 and 5 are available in the Municipal GIS project, a concurrent USAID-sponsored USGS project that will integrate maps, orthorectified aerial photography, and other available natural resource data for a particular municipality into a common geographic database. The GIS project, which is located on a computer in the Tocoa municipality office, allows users to view the GIS coverages in much more detail than shown on figures 1 and 5. The GIS project will also allow users to overlay other GIS coverages over the inundation and flood-depth boundaries to further facilitate planning and engineering. Additional information about the Municipal GIS project is available on the Internet at the GIS Products Web page (http://mitchnts1.cr.usgs.gov/projects/gis.html), a part of the USGS Hurricane Mitch Program Web site.

The GIS coverages and the HEC-RAS model files for this study are available on the Internet at the Flood Hazard Mapping Web page (http://mitchnts1.cr.usgs.gov/projects/floodhazard.html), which is also a part of the USGS Hurricane Mitch Program Web site.

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